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CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

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NO. 108

RADIATION PRECAUTIONS IN THE DEEP SPACE INSTRUMENTATION FACILITIES

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CALIFORNIA INSTITUTE OF TECHNOLOGY

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SECTION I

RADIATION PRECAUTIONS IN THE DSIF

As the NASA/JPL space exploration program is pursued, the use of high power RF radiation by the DSIF will increase, since the transmitting capabilities of the DSIF Space Communications Stations will have to reach greater distances. Transmitting capabilities are extremely important, because spacecraft are equipped with a transponder which transmits a signal at an exact multiple of its received signal frequency, and can thereby provide a means for the required precision determination of spacecraft range and velocity. Also, with transmitting capabilities available throughout the DSIF, simplification of the spacecraft is possible because command - actuated guidance and event performance equipment can be substituted for more complex internally controlled guidance and program systems.

At present all DSIF stations have transmitting capability. The Johannesburg and Goldstone Echo Stations have nominal 10-KW transmitters (13 KW CW maximum) and the Woomera Communications Station has an interim 50-watt transmitter which will be replaced with a 10-KW system early in 1963. Within the near future at Goldstone an additional transmitter installation will provide a radiated power capability of 100 to 200 KW and a maximum future capability of 350 KW at 2120 mc/s is planned.

As the DSIF use of high power radiation increases, necessary precautions will be initiated at the DSIF stations. At the Goldstone Echo Station (Figure 1), the first transmitter installation in the DSIF, information on radiation densities and safe working limits has been determined and will be applied at the other Stations.

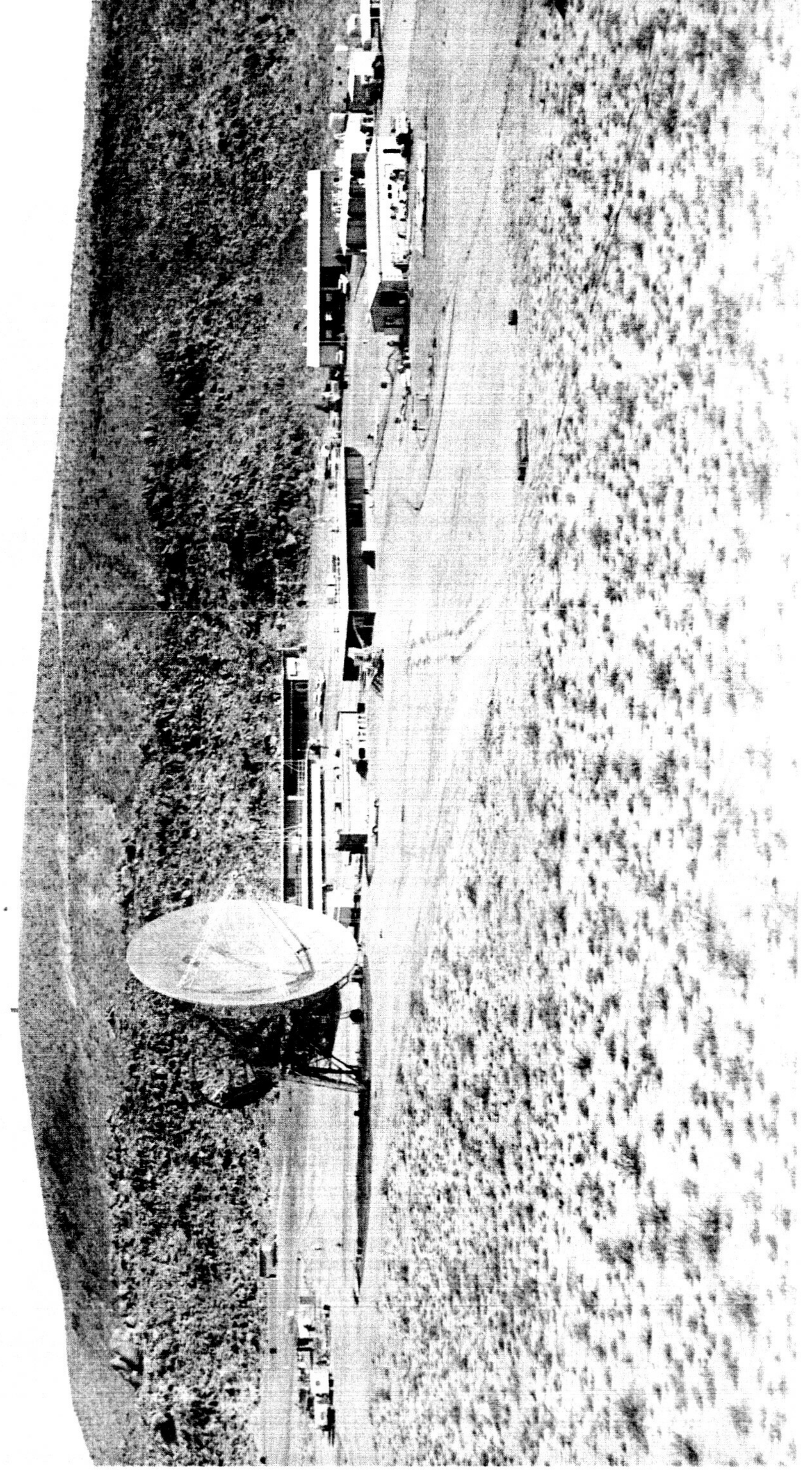

Figure 1. Goldstone Echo Station

SECTION II

EFFECTS OF RADIATION

Radiation affects both personnel and equipment which are sensitive to heat and/or RF energy. At a particular frequency the radiation effects will be determined primarily by the strength of the field and the duration of exposure.

A. EFFECTS ON PERSONNEL

External and internal body damage can result from the absorption of radiation. The absorbed energy from radiation results in heating of body tissue and temperature rises that are capable of producing biological damage. The principal types of damage that are presently of concern are: whole body heating, lenticular damage to the eye (cataracts), and testicular damage (Ref. 1). Electromagnetic radiation heats the body tissue rather than the surface of the skin. If the normal body cooling functions such as blood circulation and perspiration cannot carry away this heat fast enough, the temperature in the tissue may become sufficiently high to cause permanent injury. The eyes (Ref. 2) and testes (Ref. 3) have been considered especially vulnerable to this damage because of their relatively inefficient conduction of heat to surrounding tissues. Also, irradiation of the abdominal organs, which lack adequate blood supply for temperature regulation, may be particularly serious (Ref. 4) and it is also likely that tissues adjacent to metal implants may reach excessive temperatures during exposure (Ref. 3).

The amount of energy absorbed governs the biological effects of radiation. Energy absorption is dependent upon the "power density" or intensity of radiation, which is the amount of power per unit area of the radiation field and may be stated in watts per unit body area (watts/cm^2) or watts absorbed by the entire body. The amount of energy absorbed in the body governs the heat released in the tissues. As the amount of energy absorbed is increased, the heating of the tissue is also increased. Although the duration of exposure and the rate of blood circulation are also factors that determine the temperature ultimately reached, no data has been published on the correlation of these factors.

B. EFFECTS ON EQUIPMENT

At the Goldstone Space Communications Stations the equipment which would conceivably be affected by radiation would be equipment aboard commercial or military aircraft which might pass through the RF beam. Radio equipment is standard equipment on aircraft, and the manner in which it might be affected would depend on many factors, but primarily the type of equipment and the characteristics of the incident radiation. Other RF-sensitive devices which might be aboard aircraft, especially military aircraft, are ammunition and explosive squibs, and these devices would be sensitive to the heating effect of radiation.

SECTION III

RADIATION CHECKS AND PRECAUTIONS USED AT THE GOLDSTONE SPACE COMMUNICATIONS STATIONS

The initial installation of the transmitter at the Goldstone Space Communications Stations was paralleled by the adoption of precautions for protecting personnel from excessive radiation. As increased radiation capability is added to the Communications Stations these precautions are revised to maintain radiation-safe working conditions. The precautions used are:

A. RADIATION CHECKS WHILE THE TRANSMITTER IS IN OPERATION

The DSIF criteria used are: for continuous exposure the radiation intensity must be less than 1 mw/cm^2 and for intermittent exposure must be less than 10 mw/cm^{2*}. These exposure criteria are more conservative than those established by the U.S. Armed Forces. (The Bureau of Medicine has tentatively established a working level of 10 mw/cm^2 as the tolerable dosage for constant exposure). Using the DSIF criteria, during normal high power operations, certain areas (i.e., on the antenna dish, in the radiated RF beam and in the optical cage at the rear of the antenna reflector structure) are classified as unsafe. When, instead of an operational system, a test system is used on the antenna, and also, when adjustments in the test system cause changes in the antenna radiation pattern, monitoring devices (Figures 2 and 3) are used to measure experimentally the power density and determine the unsafe areas. These measurements are normally performed first at reduced transmitter power to eliminate hazard to persons making the measurements. The monitoring devices have meters which are easily visible and permit the individual making the checks to quickly determine the radiation level in the antenna area. If excessive radiation is indicated, for full power radiation a linear extrapolation of the reduced

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* We adopt the following definitions: Intermittent Exposure - no more than 1 hour exposure out of 24 hours; Continuous Exposure - Indefinitely prolonged exposure, 24 hours/day.

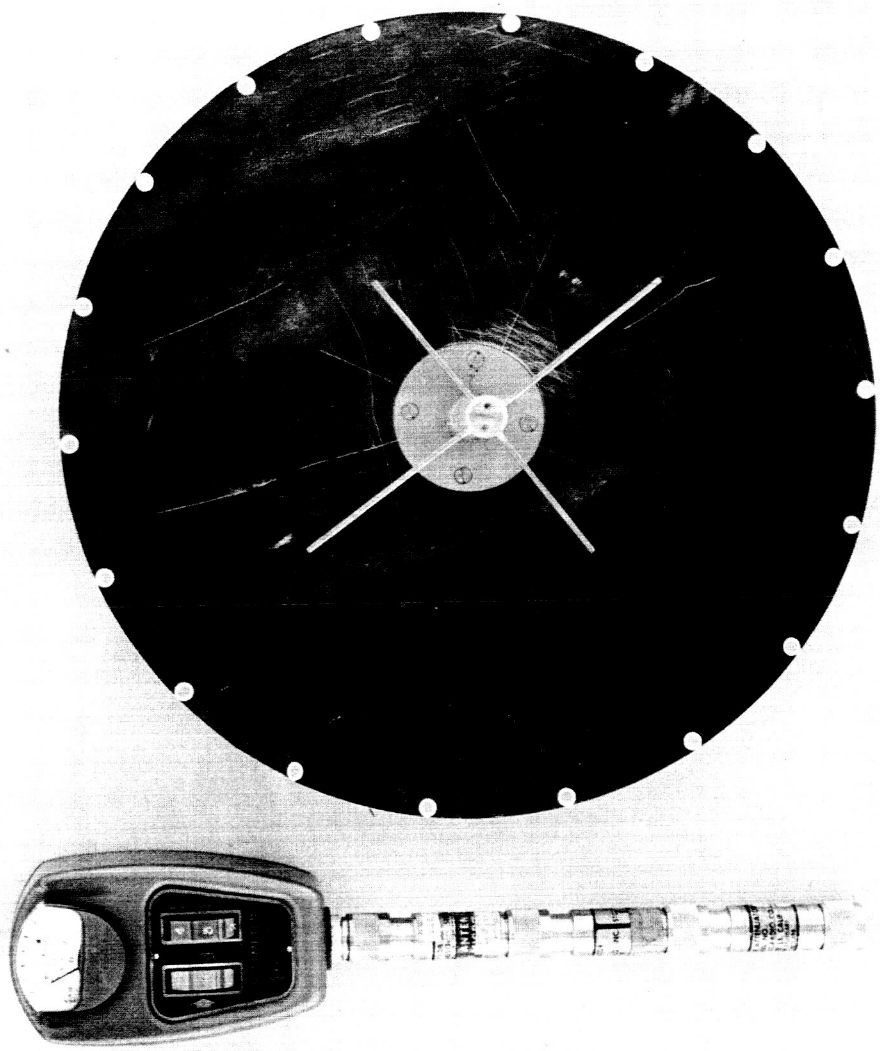

Figure 2. Ramcore Model 1300 Portable Wattmeter
(Monitor Used at Echo Station.)

Figure 3. Radiation Detector Used at the Johannesburg Communications Station

power measurements is used. When a danger area is detected, station personnel are warned over the public address system to stay out of this area and standard warning signs are posted. (See next paragraph).

B. WARNING DEVICES

Red warning lights and "warning" signs are located at strategic areas to indicate danger. Blinking red lights are placed around the 85-ft antenna to indicate that the transmitter is in operation and that unauthorized personnel should not be in the area. Signs are posted at the Hydro-Mech Building (near the base of the antenna), and in the vicinity of the antenna to warn of radiation danger. Each time the transmitter is energized for testing, used in support, or used in a tracking mission, site personnel are warned over the public address system to stay away from the antenna area.

C. WARNING NEARBY MILITARY AIRFIELDS

A report of Goldstone Transmitter operation is submitted each week to Fort Irwin. This report enables Fort Irwin to warn military airfields in the adjacent area of the radiation danger existing over the Goldstone DSIF area if the aircraft fly through the beam. (At this time, no commercial aircraft fly over Goldstone as it is a military restricted area).

D. PERIODIC EYE AND PHYSICAL EXAMINATIONS

A complete eye and physical examination is performed on all site personnel assigned duties in operations involving microwave facilities or in areas where they may be exposed to radiation hazards. Re-examinations are made at intervals of from 9 to 12 months (or sooner if necessary) to determine the physical fitness of personnel. All site personnel are required to immediately report to the site manager any eye or unusual body ailment that may have been caused by RF radiation.

E. SAFETY COMMITTEE

It is the assigned duty of the Goldstone Safety Committee to investigate all possible hazardous radiation conditions and take appropriate action. This committee has just been newly formed, but is expected to aid in the control of radiation hazards.

F. SAFETY RULES FOR SITE PERSONNEL

Safety rules which have been established are as follows:

1) Never enter an area posted for RF radiation hazard without verifying that all transmitters have been turned off and will not be turned on again without ample notice.
2) Never look into an open wave guide which is connected to an energized transmitter.
3) Never climb poles, towers, or other structures into a region of possible high radar field without verifying that all potentially dangerous transmitters have been turned off.

G. FIRST AID PROCEDURES FOR RADIATION EXPOSURE

If a person undergoes extreme whole body irradiation, the heat generated in body tissues may cause symptoms of thermal shock or heat stroke. If this should happen,a physican is called immediately, and, if necessary, the following remedial measures enacted:

1) Artificial respiration and oxygen is used if there is difficulty in breathing.
2) The body temperature of the afflicted person is returned to near normal by rapid cooling. This rapid cooling is accomplished by wrapping the person in a wet sheet and by placing an ice bag on the person's head.

SECTION IV

POWER DENSITIES AND MINIMUM SAFE DISTANCES FOR TYPICAL DSIF RADIATION SOURCES

From theoretical considerations, estimates can be made of the intensity and the effect of radiation incident upon an object or person within the antenna beam or moving through it. In practice these estimates must be verified by actual measurements of the field strength. An investigation of the characteristics and unsafe regions of the radiation fields produced at the Goldstone Echo Station has been conducted and some typical results of this investigation are presented below along with some qualifying remarks based on actual measurements.

A. DETERMINATION OF SAFE DISTANCES FOR TYPICAL RADIATION SOURCES

Assuming free-space propagation, the power density, S (watts/meter^2), at a far zone distance R (meters) on the axis of a transmitting antenna is:

$$S = \frac{P_t G_t}{4\pi R^2} \text{ watts/meter}^2 \tag{1}$$

where G is the antenna gain, and P_t is the radiated power (watts). However, if the main beam is reflected from the ground or other large reflecting surface, there will be regions where the direct and reflected fields add in-phase. In these regions, the power density can be larger than that given by Equation (1). For these cases where reflections of the main beam can occur, a safety factor of four (corresponding to the addition of a direct and reflected wave of equal intensities) is adopted.

For a maximum allowable energy density of 1 mw/cm^2 (continuous exposure criterion), the expressions for the minimum safe distance R_s become:

For no reflection paths,

$$R_s = \sqrt{\frac{P_t\, G}{4\pi \times 10}} \text{ meters} \tag{2}$$

For possible reflection paths,

$$R_s = \sqrt{\frac{P_t\, G}{\pi \times 10}} \text{ meters} \tag{3}$$

For intermittent exposure at 10 mw/cm^2, the safe distance is approximately one-third the distance given by these equations. Figure 4 shows the minimum safe ranges for continuous exposure predicted from these equations for several radiating configurations. Examples 1 and 2 below illustrate the application of these equations to two different types of DSIF radiation sources. The shortcomings of these equations are discussed in terms of radiation levels actually encountered in the vicinity of the Goldstone antenna.

Example 1. Assume a 2388 Mc transmitter radiating P_t = 13 kilowatts using a Goldstone type of 85-ft diameter antenna. The maximum possible gain G of the antenna is 422,000 (56.3 db). For free-space conditions and no reflections, the power density at a distance R on the axis of the antenna is, from Equation (1)

$$S = \frac{4.4 \times 10^8}{R^2 \text{ (meters)}} \text{ watts/meter}^2$$

If the main beam is reflected from the ground so there will be regions near the reflection point where the power density is greater than that calculated above, then Equation (3) must be used to calculate the safe distance. For continuous exposure (power density S = 1 mw/cm^2), the minimum safe distance R_s in the antenna main beam near the ground is

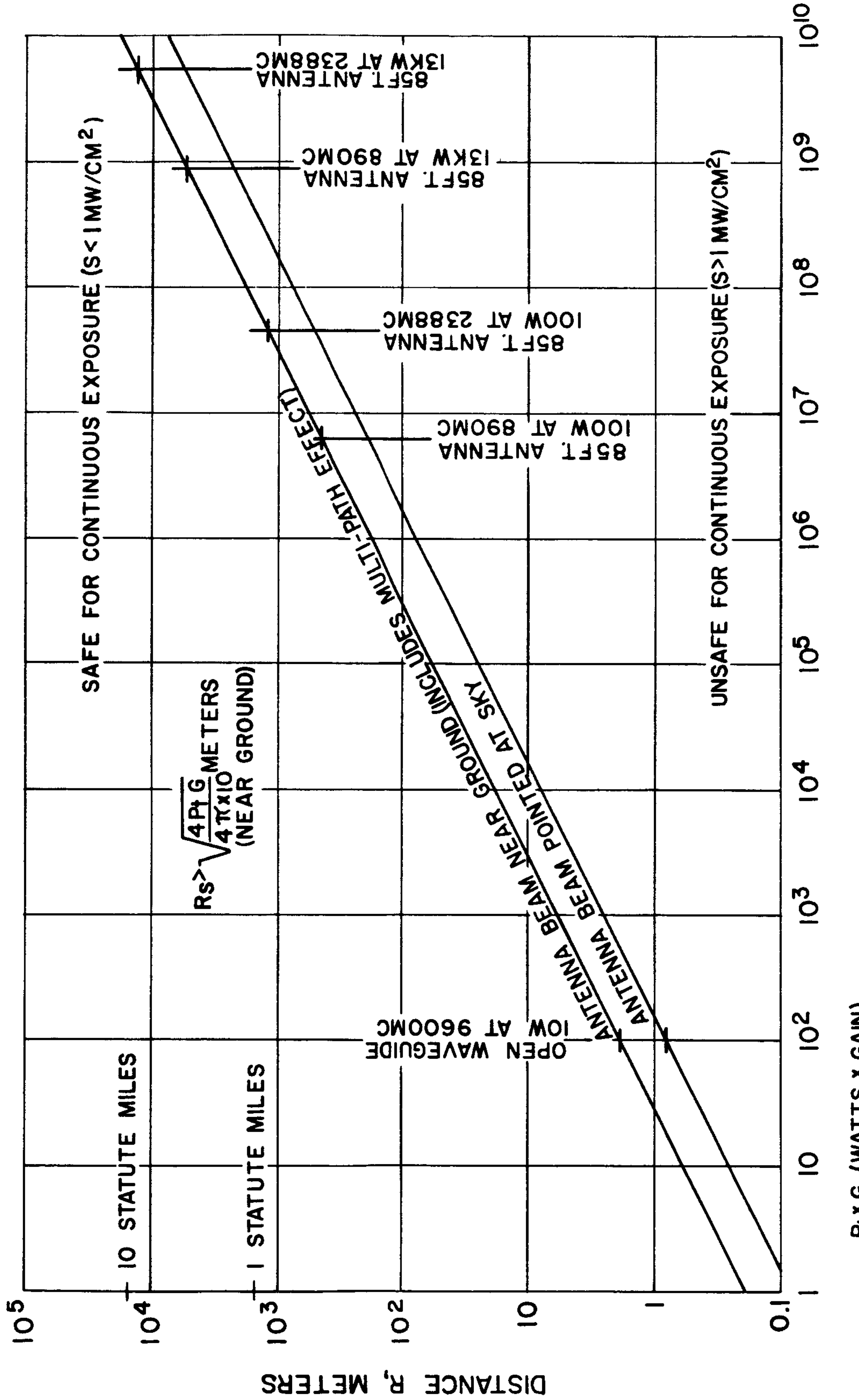

Figure 4. Minimum Safe Range for Continuous Exposure (S< 1 MW/CM^2)

$$R_s = \sqrt{\frac{P_t\, G \times 4}{4\pi \times 10}} = \sqrt{\frac{4.4 \times 10^8 \times 4}{10}} = 13,200 \text{ meters (or 8.2 miles)}$$

If the antenna is pointed into the sky, calculation from Equation (2) gives R_s = 6600 meters (4.1 miles); even at small angles (>1 deg) off the antenna axis, the power density drops rapidly. For intermittent exposure at S = 10 mw/cm^2, the R_s = 4200 meters and 2100 meters, from Equations (3) and (2), respectively. In this example, if the antenna is pointed at the top of the collimation tower about 1 mile away and 100 feet above the ground, the power density at the base of the tower is less than 2 mw/cm^2. Experimental measurements have shown that the preceding calculations are conservative, and that the major hazardous area is the area in-line with the pointing axis of the antenna within a small cone of half-angle about 1 degree or within a cylinder of the diameter of the antenna, whichever is greater.

There are many practical situations where the application of Equations (2) and (3) is obscure. For example, power measurements behind the 85 ft antenna have always shown a density, S, of less than 1 mw/cm^2 for the entire region beyond the distance of 50 feet behind the reflector. Immediately behind the reflector surface, the power density is usually less than 1 mw/cm^2; however, this area should be tested with a power density meter each time it is necessary to work there. Any new work area near the antenna or near the main beam of the antenna should be tested with a power density meter before work is allowed to start with the high-power transmitter on.

<u>Example 2.</u> Assume a P_t = 10 KW CW, 890-Mc signal generator radiating from an open-ended waveguide. The gain of the waveguide acting as an antenna is less than G = 10 (10 db). From Equation (2), for a power density S of 1 mw/cm^2.

$$R_s = \sqrt{\frac{P_t\ G}{4\pi \times 10}} = \sqrt{\frac{10,000 \times 10}{4\pi \times 10}} = 27 \text{ M}$$

If the waveguide is attached to a horn with a gain of 100, Equation (2) gives

$$R_s\ (\text{horn}) = \sqrt{\frac{10,000 \times 100}{4\pi \times 10}} = 89 \text{ M}$$

If there is a possibility of multiple reflections, Equation (3) gives $R_s = 56$ meters. For a power density of 10 mw/cm^2 for intermittent exposure, the safe distances are one-third as large.

B. RADIATION CHARACTERISTICS OF DSIF CASSEGRAIN SYSTEMS

Investigations have been made of the radiation field characteristics of the DSIF cassegrain systems. The parameters used in this investigation were:

Safe radiation level of 1 mw/cm^2
Transmitter frequency of 890 Mc
Wavelength of 13.3 inches
Average transmitted power 10 KW
Diameter of paraboloid of 85 feet
Antenna gain of 45 db
Far field limit ($2D^2/\lambda$) of 2.5 miles
Beamwidth of 0.9 degrees
f/D of 0.42
Angle subtended by subreflector from feed point of 13.5 degrees

1. On-Axis Power Density

Assuming an aperture efficiency of 3 db the on-axis average power density can be determined from the given parameters. Figure 5 shows the on-axis power density and also the normal $2D^2/\lambda$ far-field limit and the 1 mw/cm^2 continuous exposure safety limit. These plots follow the $1/R^2$ variation of equation (1) to about 0.5 miles. For values of range less than 0.5 miles S is shown independent of range. In the near field the power density actually oscillates with range, but these curves show only the average values of these oscillations: deep valleys and peaks 3 to 6 db greater than the average occur. As shown in Figure 5, the safe limit for the main beam, 1 mw/cm^2, is at a distance of 1.0 mile. Therefore, for continuous exposure in the main beam there is no safe point closer than 1.0 mile to the antenna.

2. Off-Axis Power Densities

The off-axis power densities are due to contributions from the aperture itself, main beam side lobes, feed system, subreflector effects and back radiation behind the dish.

The analysis of the off-axis fields is complicated by the fact that in the regions of interest, i.e., close to the antenna, accurate knowledge of the field must be obtained by measurement. If we assume that close to the aperture the energy is mostly contained in a cylindrical beam with cross section defined by the antenna aperture, then the power density is:

$$P = \frac{P_t}{\text{area}} = \frac{10^7}{\pi (1295)^2} = 1.9 \text{ mw/cm}^2$$

This approximate density extends to the 42.5-foot (12.95m) antenna radius, dropping off rapidly in the region outside the cylinder. In fact, at the aperture edge the power density is about 1/4 that in the center of the aperture, or equal to 0.47 mw/cm^2.

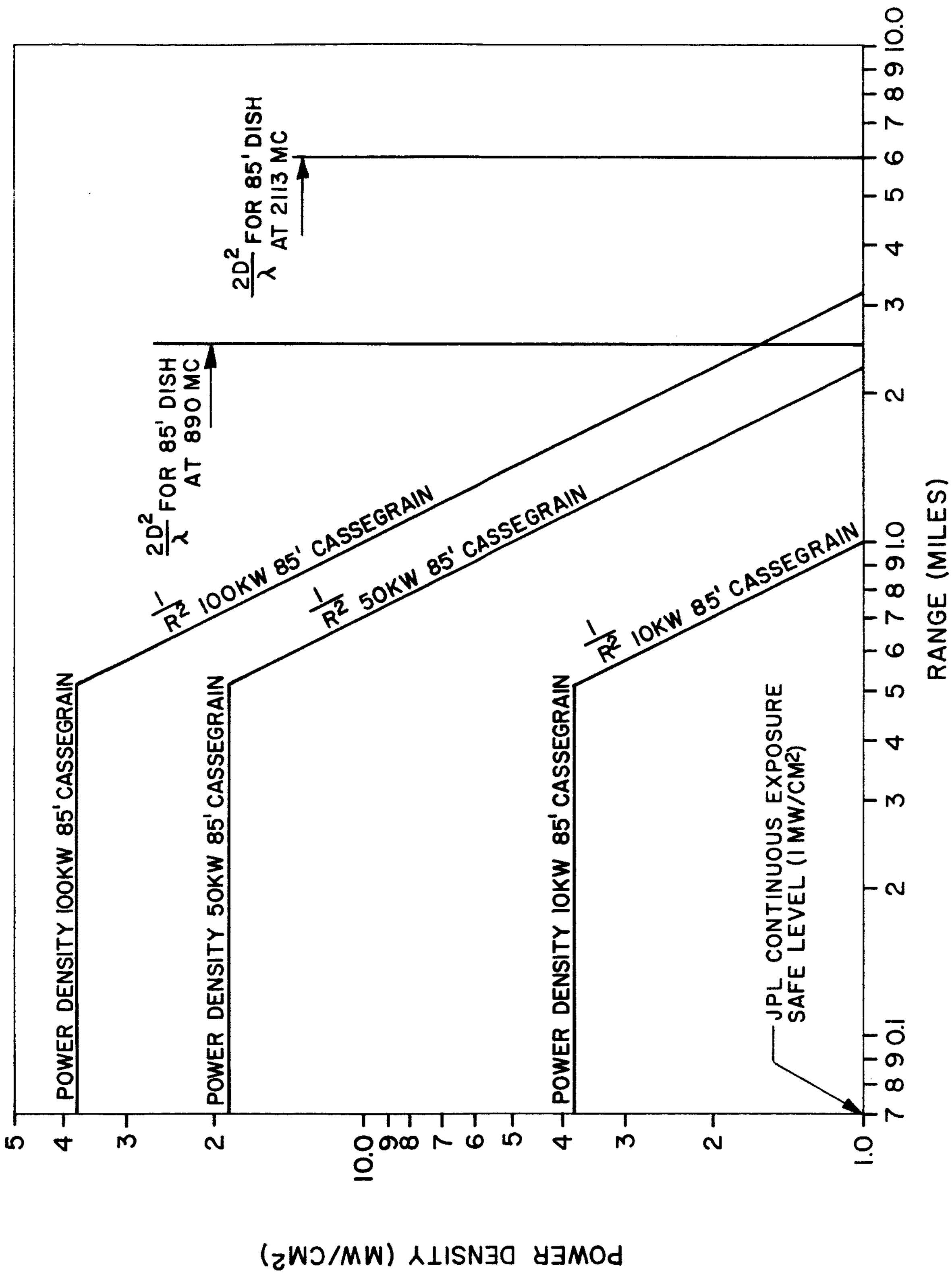

Figure 5. On Axis Power Densities for DSIF 85' Paraboloids Using Cassegrain Feed for L-Band (890 MC/S)

The side-lobe structure of the main beam will not contribute any significant energy density at far off-axis angles. About 5° off axis, these side lobes should be more than 35 db down from the peak; in the region beyond 0.1 mile from the aperture, their contribution can be neglected.

Energy from the feed system, the cassegrain horn and the subreflector, is a major factor near the antenna. For a typical proposed system, the feed system horn gain would be about 23 db in the forward direction. The spillover level past the primary reflector would be typically of order 10 db below the maximum, or 13 db above isotropic. If the energy at the subreflector is assumed to reradiate isotropically, then the energy density in the safe zone is about one-twentieth that due to the maximum spillover of the feed horn. This additional field, due to the subreflector, will be henceforth neglected.

Since the dish is to be of metal, the back radiation from the feed is no problem. However, diffraction around the dish can occur. Geometric optics predicts a "bright spot" behind a dish illuminated by a plane wave. The intensity of this maximum is less than the field would have been in the absence of the dish. It then seems to be safe to assume an isotropic radiator at the feed with the dish removed in computing the energy density in regions behind the dish. For an isotropic radiation, a computation gives a safe distance of about 18 meters assuming reflection with 10 KW radiated. Of course, in an actual operational situation this type of calculation would be verified by experimental measurement.

Thus for the parameters used (10 KW, 890 Mc, 85-ft diameter antenna) and neglecting the primary feed spillover the zone unsafe for continuous exposure is bounded by a sphere with an approximate 18 meter radius and a 25.9 meter (85-ft) diameter cylinder concentric with the beam axis and 1 mile long. The primary feed spillover, of the order 3-13 db above isotropic, will extend the 18 meter radius of the sphere by a factor of 1.4 - 4.5 times in range in particular directions depending on the feed type used (determined by approximate analysis and experimental measurement).

C. DYNAMIC EXPOSURE TO RADIATION

Because of the size of the region where the radiation density is greater than 1 mw/cm^2 estimates of the allowable duration of passage for personnel and RF sensitive equipment (i.e., explosive squibs) aboard aircraft have been made.

1. Consideration of the Danger to Personnel Aboard Aircraft [1)]

The danger to personnel aboard aircraft is determined by the time of exposure to the RF field. The effect of the time of exposure on the threshold for RF radiation damage has been studied by a number of researchers. (See bibliography by Mumford, Reference 5).

Figure 9 of Reference 5 has been reproduced here as Figure 6 to show the preliminary estimates of Ely et al. regarding threshold power densities (versus time) of three sensitive structures; the eye, the whole body, and the testes of a dog. Quoting from Mumford:

> "The downward slope at short exposure time is based on their estimates of the thermal time constant of the structure. The terminal power density for long exposure is determined by the heat exchange characteristics of the structure and an estimated tolerable terminal temperature which was assumed to be 102.2°F for the whole body, 113.0° for the eye, and 98.6°F for the testes. The power densities required to maintain these "tolerable" temperatures are 100 mw/cm^2 for the whole body, 155 mw/cm^2 for the eye, and 5 mw/cm^2 for the testes."
>
> "Note that the only threshold power density level which is lower than the currently adopted potentially hazardous level of 10 mw/cm^2 is that for the testes, 5 mw/cm^2".

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1) Addendum A presents a discussion of the disruptive effects an aircraft could have as it passes through the antenna beam during an operation.

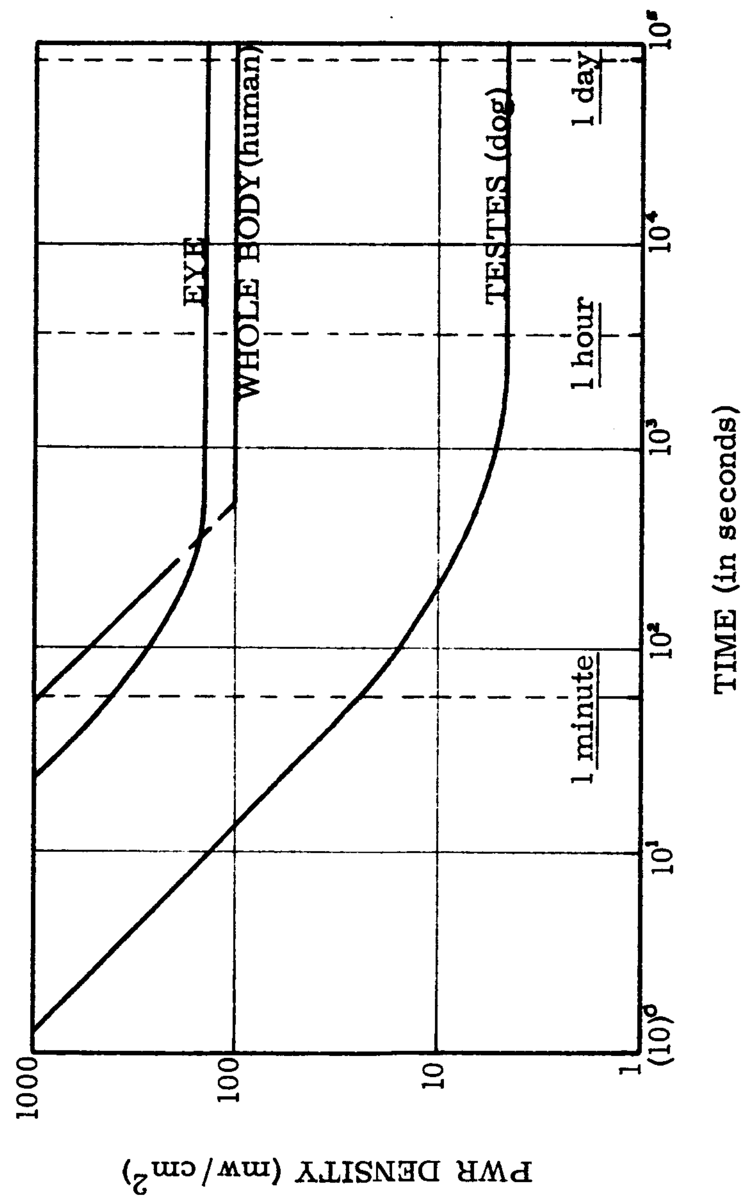

Figure 6. Threshold Levels vs Time for three sensitive structures (Figure 9 of Reference 5)

(Note that this was determined in tests with dogs requiring exposure times of almost 15 minutes and the human circulatory system is more efficient).

> "The question naturally arises, just how tolerable or how hazardous is a temperature of 98.6°F in the testes?"

Ely et al comment on this point thus, "Although the criterion of hazard used in this study (of testicular changes) has been the least demonstrable damage, other factors should be considered in the over-all viewpoint. The minimal testicular damage is almost certainly completely reversible. Even considerably more severe testicular insult will probably be reversible, with the only finding being a temporary sterility. An even greater injury can result in permanent sterility, which result would evoke varying reaction". (Quote from Reference 5).

An estimate of the hazards for short term exposures can be made from Figure 6. It appears that a 10 second exposure requires power densities in the range of 150 to 3000 mw/cm^2 to reach the various thresholds for hazardous exposure. A 100 second exposure requires 15 to 600 mw/cm^2. To be conservative the Bell Telephone Laboratories have adopted a safety limit of 10 mw/cm^2 for occasional exposure. (In 1956, H. P. Schwan stated that 10 mw/cm^2 should not be allowed for more than one (1) hour).

Consider the hazard to aircraft passengers flying through a high power transmitter antenna beam. We may simplify the antenna geometry as in Figure 7. In this case is is assumed that most of the radiated power is contained in a cylinder as long as the safe range (R_s) for a power density of 10 mw/cm^2. We may define the diameter (d) of the cylinder in various ways. One method is to set the diameter equal to the distance between the half power points of the antenna beam at the range R_s. Then the diameter of the cylinder is

$d = R_s \tan \beta$, where R_s = the safe range for a power density of

$S = 10\ mw/cm^2$

β = the antenna half power beamwidth

B. F. LaPage of the M. I. T. Lincoln Laboratory has made similar calculations.

As examples consider the current 10 KW, 890 Mc system, the planned 10 KW, 2113 5/16 Mc system and two possible future very high capability systems. For an 85-ft paraboloidal antenna

at 890 Mc, $\beta = 0.94°$
at 2113 5/16 Mc, $\beta = 0.40°$
at 2388 Mc, $\beta = 0.35°$
at 8459 Mc, $\beta = 0.10°$

as before

$$R_s = \sqrt{\frac{P_t G_t}{4\pi S}}$$ (assuming no shielding by the aircraft fuselage)

For a transmitted power of 10 KW at 890 Mc,

$$R_s = 0.54 \text{ km}$$

For a transmitted power of 10 KW at 2113 5/16 Mc,

$$R_s = 1.26 \text{ km}$$

For a transmitted power of 350 KW at 2388 Mc,

$$R_s = 8.4 \text{ km}$$

For a transmitted power of 175 KW at 8450 Mc,

$$R_s = 18.7 \text{ km}$$

The time (T) an aircraft will be in the antenna beam will be (see Figure 7)

$$T = \frac{L}{v}, \text{ where the distance } L = \frac{d}{\sin \alpha}$$

α = the elevation angle of the antenna

v = the aircraft velocity

Finally, $$T = \frac{R_s \tan \beta}{v \sin \alpha}$$

Substituting the values given above for range and beamwidth and assuming an aircraft flying at 100 mph and an antenna elevation angle of 5° (the minimum angle possible for high power transmission) we have

at 890 Mc,	T (maximum) = 2.3 seconds
at 2113 5/16 Mc,	T (maximum) = 2.3 seconds
at 2388 Mc,	T (maximum) = 13 seconds
at 8450 Mc,	T (maximum = 8.3 seconds

For higher aircraft speeds or antenna elevation angles, the time in the beam will decrease.

Referring again to Figure 6, we find that, for times as short as 20 seconds or less, 10 mw/cm^2 is an ultra conservative level. It would appear that 40 mw/cm^2 should be safe for this length of time. Considering the other conservative assumptions such as maximum time in the beam (an unlikely occurrence), a slow aircraft speed of 100 mph and no aircraft shielding of the passengers it should not be hazardous to reduce the safe distances to:

Maximum Transmitter CW Power (kw)	Frequency (mc)	Safe Range (km)
10	890	0.27
10	2113 5/16	0.63
350	2388	4.2
175	8450	9.3

Safe ranges for other frequencies and powers can be calculated using the above principles.

2. Danger of Explosive Squib Ignition

Explosive squibs are used aboard some military aircraft to initiate various release devices. A typical squib may be about 1 inch long with a pair of leads attached. Inside the squib these leads are connected to a small wire filament which is in contact with a small explosive charge. The squib, whose explosive power is of the order of a Fourth of July cherry bomb, is ignited when the filament converts a small amount of electrical energy to heat.

The electrical energy for ignition may be supplied from a direct current or radio frequency source; the conversion of electrical energy to heat can be just as efficient. However, if the electrical power or the rate of supply of energy is too low, the filament will never reach the required temperature since it is cooled by its surroundings. Thus, there is a minimum power as well as a minimum total energy required for ignition, and in determining whether the pulsed energy typical of radar would cause ignition, the average power must be considered rather than the peak power. (Unless sufficient energy is introduced to cause ignition in one very long pulse; then the peak power should be considered).

Since the squib firing harness can act as an antenna it could supply RF energy to the squib. An estimate of the maximum amount of power which a receiving antenna of effective area A_e can extract from an electromagnetic wave of energy density S is given by:

$$P_r = A_e \cdot S \tag{4}$$

where P_r is the power available at the antenna terminals.

The effective antenna area A_e is related in a general way to the physical area of the "antenna".

Sufficient information is not currently available at JPL, about the types of squibs used on military or civilian aircraft or the shielding protection provided for them, in order to make appropriate calculations for safe distances. Information of that nature plus the information contained in this memo would allow calculation of the minimum safe range to prevent accidental ignition of squibs. The type of calculations required to determine this minimum safe range can be illustrated with values used at JPL for safety calculations for low-power-sensitive squibs. At JPL the following assumptions are made:

a. A squib harness with long untwisted, unshielded leads has a maximum effective area (A_e) of one square meter.
b. For squib ignition both the following are required:

    1) A minimum power, P_r (minimum), of 0.1 watts.
    2) A minimum total energy, U (minimum), of 0.03 watt-seconds, i.e., U (minimum) = (P_r) (Time).

From these assumptions, 0.1 watt is the dominant available power requirement, since for all exposure times greater than 0.3 seconds, P_r (minimum) is required, and, for all exposure times less than 0.3 seconds (these times correspond to a high aircraft speed, high antenna elevation case in Figure 7), the power required to obtain U (minimum) is greater than 0.1 watt. The required energy density is then:

$$S = \frac{P_r}{A_e} = 0.1 \frac{\text{watts}}{\text{meter}^2} \text{ (sensitive squib, no shielding)}$$

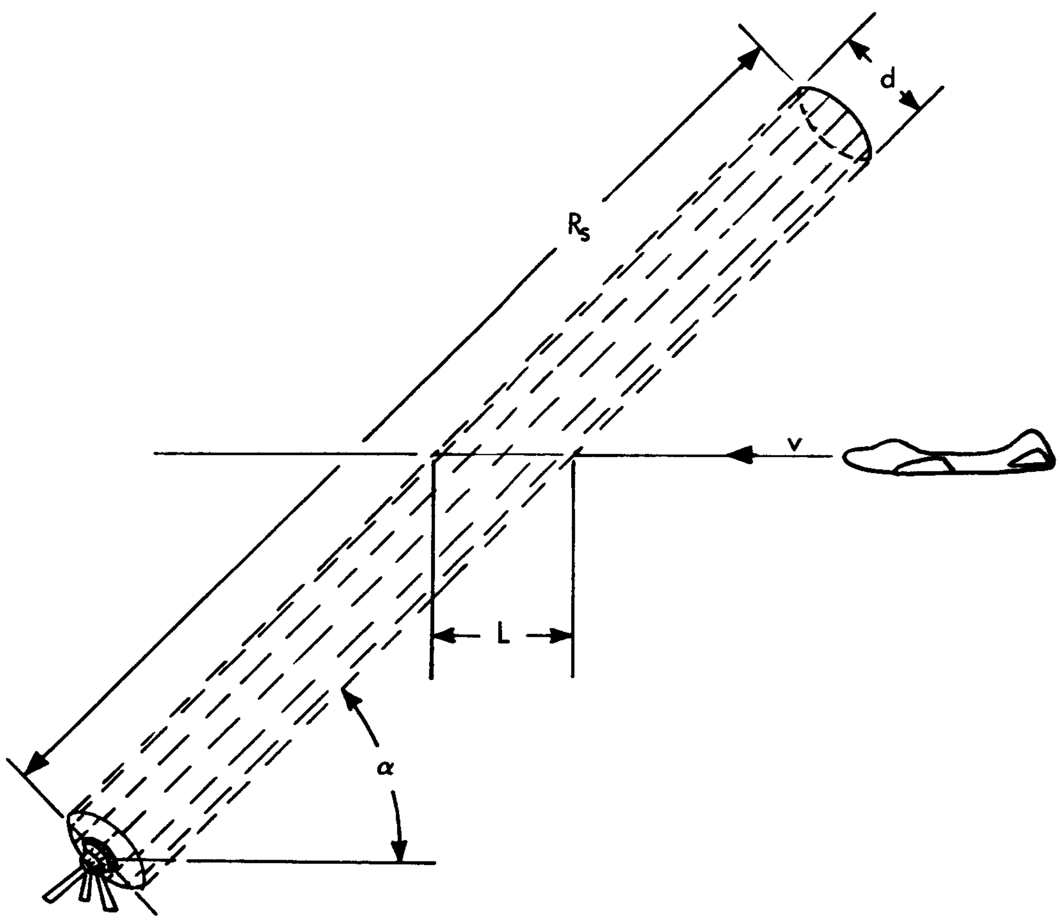

Figure 7. Assumed Radiation Pattern for Aircraft Exposure

S might be improved by 40 db or more by using squibs requiring higher ignition power and by proper shielding of the harness. Then:

$$S = 10^3 \frac{\text{watts}}{\text{meter}^2}$$

and the minimum safe range

$$R_s = \sqrt{\frac{P_t G_t}{4\pi S}} = \sqrt{\frac{P_t G_t}{4\pi \times 10^3}}$$

Therefore at 890 Mc, with

P_t = 10 KW and G_t = 3.5×10^4

R_s = 0.17 Km,

at 2113 5/16 Mc, with

P_t = 10 KW and G_t = 2.0×10^5

R_s = 0.40 Km,

at 2383 Mc, with

P_t = 350 KW and G_t = 2.5×10^5,

R_s = 2.64 Km and

at 8450 Mc, with

P_t = 175 KW and G_t = 2.5×10^6,

R_s = 5.9 Km

These numbers are only examples, and are not necessarily valid for any specific case. The correct numbers can be calculated only using the parameters of the actual squibs and their circuits and shielding.

D. SUMMARY

When the decision was made to equip the DSIF stations with transmitting capability it was realized that precautions would have to be taken to prevent any harmful effects on personnel or equipment. Experience at the initial transmitter installation at the Goldstone Echo Station has shown that the radiation field produced is such that, with the use of proper operating procedures and the adoption of proper personnel protection standards, there is no danger to either personnel or equipment.

Safe distances from the Goldstone transmitting antennas have been calculated for a number of situations, using the best practical techniques and the best estimate of biological hazard levels currently at hand. Table I summarizes the results for cases of specific interest at this time.

Table I. Safe Distances for Specific Goldstone Transmitting Configurations
(Biological Hazard Considerations)

Radiation Configuration	Safe Distance (km) for Aircraft in Beam (short exposure)	Safe Distance (km) for Intermittent Exposure in Beam	Safe Distance (km) for Continuous Exposure in Beam
10 KW, 890 Mc, 85' Antenna (current operational system)	0.27	0.54	1.7
10 KW, 2113 5/16 Mc, 85' Antenna (planned operational system)	0.63	1.26	3.95
350 KW, 2388 Mc, 85' Antenna (possible future system)	4.2	8.4	26.5
175 KW, 8450 Mc, 85' Antenna (possible future system)	9.3	18.7	59.0

NOTE: Calculations based on direct free space transmission (no reflections), 40 mw/cm^2 maximum power density for short exposure times (<20 sec), 10 mw/cm^2 maximum for intermittent exposure, 1 mw/cm^2 for continuous exposure. See text for methods and assumptions.

ADDENDUM A

AIRCRAFT INTERFERENCE WITH SPACECRAFT COMMUNICATIONS AND PLANETARY RADAR

For very low noise maser receiving systems of the type in use at the Goldstone Pioneer Station there is a possibility of interference from sources of RF radiation. One prime source of interference could be the RF equipment aboard an aircraft (other sources of interference would be TV and radio stations, radar sites, factories, congested highways with ignition noise, police radios, etc.). Interference from aircraft equipment may enter the maser frequency bandwidth due to harmonics of the transmitted interference signal or due to the broadband noise present as a low background in many transmitters. The best protection in the past for sensitive receivers has been to choose isolated antenna sites away from sources of man-made interference. For this reason remoteness from high density air traffic routes was a factor in the location of the DSIF Station at Goldstone.

Location of the Goldstone Space Communications Stations at a distance from high density air traffic has also lessened the possibility of another type of aircraft-caused interference. An aircraft flying through the antenna beam during a spacecraft tracking mission may reduce the amplitude of the received signal and cause serious phase distortion. For example, at 10 kilometers range, the effective diameter of the antenna beam will be between 200 feet and 85 feet at 2388-mc and 8450-mc respectively. This yields effective areas of about 500 to 2900 square meters. Average aircraft cross sections measured by radar back scattering are assumed to be in the range of 10 to 100 meters. The effective forward blockage area of an aircraft however, is more nearly proportional to the physical projected area and may be of the same order of size as the antenna beam. The probability of an aircraft intercepting the antenna beam is fairly low and the time of crossing is a matter of seconds, but it might occur at the time of a critical transmission to or from the spacecraft.

During lunar or planetary radar experiments when a receiver is used in conjunction with the transmitter, the effect of an aircraft crossing the beam would be greater because of the radar system sensitivity to the resulting signal scattering (backward in this case). The effect can be estimated from the radar signal equation:

$$P_r = \frac{P_t G^2}{(4\pi)^3} \cdot \frac{\sigma \lambda^2}{R^4}$$

where σ = the effective cross sectional area of a radar target for backward scatter of the signal

P_r = received power

λ = the wavelength

The other terms have been defined.

The important thing about the equation in this case is the inverse dependence of received power on range (R) to the fourth power. An aircraft might be 10 to 20 kilometers away while the moon is 400,000 kilometers distant, and Venus is farther than 35,000,000 kilometers.

Taking into account the size of the Moon, the reflection coefficient, and assuming an aircraft radar cross section of 10 meters^2 at a range of 20 km, the aircraft would return a signal more than 64 db stronger than the Moon if both were centered in the antenna beam. The antenna does not have a perfect pencil beam but has sidelobes falling off in amplitude at increasing angles away from the main beam. This means that at 2388 mc, the aircraft might cause interference anywhere in a 10° cone centered on the main beam.

Although Venus is so much farther away that the reflected signal is of the order of 60 to 70 db less intense than that of the Moon the scattered signal from an aircraft will probably not affect a planetary radar experiment. Unless the Earth and Venus are near orbital conjunction the frequency of the returned signal will be quite different from the transmitted frequency because of doppler effects. Since narrow band receivers are used in observing Venus the interference scattered signal would be rejected unless it had the same doppler shift as the returning signal. This could only occur near orbital conjunction.

For other planets, in particular Mars, relatively wide band receivers must be used in the radar system due to a radar effect known as doppler broadening. In this case, back scattered signals from aircraft may cause interference over a very large angular region around the main beam.

REFERENCES CITED

1. Mac Murray, L. E. et. al. Health Hazards Associated with Microwave Radiation, Paper Presented at Meeting of American Conference of Governmental Industrial Hygienists, (April, 1958).

2. McLaughlin, J. T., Tissue Destruction and Death from Microwave Radiation, California Medicine, Vol. 86, p. 336-39 (May, 1957).

3. Marchand, N., Health Hazards of High Frequency Radiation (Microwave). 26th Annual Safety Convention, Greater New York Safety Council

4. Hines, H. M., and Randall, J. E., Possible Industrial Hazards in the Use of Microwave Radiation, Electrical Engineering, P. 874-881. (October, 1952).

5. Mumford, W. W., Some Technical Aspects of Microwave Radiation Hazards, Proceedings of the I.R.E., Institute of Radio Engineers, 1 East 79th Street New York (February, 1961).

ADDITIONAL REFERENCES

Kovacs, R., Electrotherapy and Light Therapy, Lea Fiberger, Philadelphia, Pa. (1938).

Induction and Dielectric Heating Processes, Special Hazards Bulletin #Z-4, Association of Casualty and Surety Companies, New York, N. Y. (1948).

Industrial Use of X-Ray and Radium, Special Hazards Bulletin#Z-14, N.Y. (1949).

Medical Use of X-Ray and Radium, Special Hazards Bulletin #Z-19, Association of Casualty and Surety Companies, New York, N.Y. (1949).

Egan, W. E., Eye Protection in Radar Field, Electrical Engineering p. 126-127, (Feb., 1957).

Anon, Radar and Rocket Fuel Pose Few Hazards, Public Health Reports, vol. 74, no. 3, p. 215-216, (March, 1959).

Hirsch, G., and Parker, T., Bilateral Lenticular Opacities Occuring in a Technician Operating a Microwave Generator, AMA Archives of Ind. Hyg. and Occ. Med., vol. 6 p. 512-517, (Dec. 1952).

Fueling Aircraft on the Ground Including Recommendations on Aircraft Fueling Hose and Aircraft Fuel Servicing Tank Vehicles, NFPA No. 407, National Fire Protection Association, Boston, Mass. (May, 1957).

Barron, C.I., and Baraff, A. A., Medical Considerations of Exposure to Microwaves (Radar) Journal of the American Medical Association, vol. 168 no. 9, 1194-1199, (November 1958)

Merrick, J. F., and Krusen, F. A., Certain Physiological and Pathological Effects of Microwaves, Electrical Engineering, p. 239-243 (March, 1953).

Boysen, E. Hyperthermic and Pathological Effect of Electromagnetic Radiation (350 MC), AMA Archives of Ind. Hyg. and Occ. Med. vol. 7, no. 6, p. 516-525, (June, 1953).

Rieke, F. E. Unplanned Radio-Wave Diathermy at the Place of Work, Industrial Medicine and Surgery, (September, 1954).

Cogan, D. G., et. al., Cataracts and Ultra-high-frequency Radiation, AMA Archives of Ind. Health, Vol. 18, no. 4, p. 299-302, October, 1958).

Code of Federal Regulations, Title 47, Telecommunications, Part 18.

Morgan, W. E., Microwave Radiation Hazards, AMA Archives of Industrial Health, p. 570-73, (June, 1960).

Lubin, W. et. al., Effects of Ultra High Frequency Radiation on Animals, i.b.i.d. p. 565-68.

Green, E. I., Fisher, R. J., Ferguson, J. C., Techniques and Facilities for Microwave Radar Testing, A.I.E.E. Transactions, American Institute of Electrical Engineers, 33 West 39th Street, New York (May, 1946).

Griesheimer, R. N., Techniques of Microwave Measurements, M.I.T. Radiation Laboratory Series, McGraw Hill Publishing Co., New York, p. 79-218 (1947).

Sucher, M.A., Comparison of Microwave Power Measurement Techniques, Proceedings of Symposium on Modern Advances in Microwave Techniques, Brooklyn Polytechnic Institute, Brooklyn, N. Y., p. 309-23, (Nov. 1954).